Southern Plains Inventory and Monitoring Network
Report from the Grassland Workshop
February 1-2, 2005
Hosted by Washita Battlefield NHS
Coyote Hills Guest Ranch, Cheyenne, Oklahoma

OVERVIEW

This two day workshop was part of the process to develop a long-term ecological monitoring program for natural resources in the Southern Plains Inventory and Monitoring Network (SOPN). Developing conceptual models is one of the first steps towards selecting a suite of efficient and cost-effective indicators ("vital signs") of ecological integrity. During the first day draft versions of the grassland conceptual models were presented by Dr. Dan Tinker and then given a thorough review by workshop participants. The second day used the previous day's discussion of conceptual models as a framework to develop a list of potential grassland vital signs for SOPN. The workshop was attended by 26 people, including 12 outside experts and at least one representative from all 11 SOPN parks (Table 1 - Final Participant List).

OBJECTIVES

1) Review grassland conceptual models. Provide model developer with suggestions for modifications and possible additional models.
2) Review the important natural resources and stressors of the network.
3) Develop/review list of potential vital signs with preliminary justification statements and monitoring objectives.

CONCEPTUAL MODEL REVIEW

Dusty Perkins started the day with an introductory talk on the Inventory and Monitoring Program and the Southern Plains Network. Then Dan Tinker presented his draft conceptual models (Appendix 1 for a description of the models presented). Then workshop participants were divided up into a short-grass (facilitated by John Gross) and a mixed-grass (facilitated by Dan Tinker) breakout group. Each group was assigned to review the models that corresponded to their breakout group. Due to the similarity of the short-grass and mixed-grass models, many of the comments made by each group were relevant to the other model. A complete report of the notes of each breakout group, comments made on conceptual model forms, and comments written on the conceptual model posters are in Appendix 2.

Conceptual Model Summary and Future Directions

This section briefly summarizes the major comments and concerns of the workshop and provides an outline of revisions to the existing models and the new models that will be developed jointly by Dan Tinker, Ann Hild and SOPN staff.

Many workshop attendees wanted to see more process-based (mechanistic, state-transition) models that they thought would be more useful to them in management decisions and for understanding the system for use in vital signs development and selection. These types of models will do a better job of showing the temporal and spatial effects of the stressors, which is hard to show in the stressor models that were presented. Specifically these types of models should be developed to address and include grazing, fire, keystone species, land legacies, and their major interactions.

There was some debate about the usefulness of conceptual models for park management. If models were customized to an individual park, they would lose their usefulness to the network because they would be so specific. It would take a large amount of resources to create 11 conceptual models for grasslands at each individual park. Conceptual models are not intended to be a guidebook for managers on specific management practices, but should be designed so they are helpful in understanding the system and understanding the potential implications of management practices. The solution will be to develop conceptual diagrams that are customized to a group of parks or in some cases, individual parks. These diagrams will highlight the important components of the mechanistic grassland models.

There was discussion about how cultural resource management issues that are affected by natural resources fit into models and potential vital signs (e.g. prairie dogs effects on Santa Fe trail ruts, small mammals burrowing under ruins, landscape composition as it relates to viewsheds). These types of issues are hard to represent in conceptual models because they are often so specific.

There was debate in both groups over whether a species-specific keystone model incorporating prairie dogs should be developed. SOPN staff has decided to pursue this type of model due to this species' importance for biological, cultural and management reasons for at least five parks. We will first look to literature for examples.

The models currently ignore decomposition/microbial/soil animal interactions. This may be acceptable if: a) impacts are adequately captured by other interactions displayed in the model, and b) the fossorial biota in this group doesn't radically change soil processes and trophic levels (e.g. invasive earthworms in riparian zone). Revisions to stressor models and all future models need to be sure these impacts are included.

Future Directions for Grassland Models:

SOPN staff and the grassland model PIs will work collaboratively on the grassland models to do the following:

1.) Adopt the Jenny-Chapin model as the overarching conceptual model for the Southern Plains Network (Figure 1).
2.) Develop mechanistic/state-transition/process model(s) for grazing and fire and their interactions (Figures 2-4 are examples of these types of models). These models should be modified to fit short- and mixed-grass systems. These models should also incorporate what is currently depicted in the vegetation dynamics and successional stressor submodels. Fire and grazing models should capture variables such as time of year, extent, intensity of fire and grazing, and could potentially incorporate thresholds in a state-transition type model (such as woody species invasion, prairie dog colony expansion, invasive species invasion, etc.). The model(s) should also include land legacy, or the current land condition (agricultural field, prairie fragment), since certain conditions are harder to restore than others (farmland is harder to restore than ranchland because the soil has been disturbed).

-Westoby et al. Journal of Range Management was suggested as a good state-transition model for fire and grazing
-For a basis for exotics and woody invasives, Evans et al. 2001 had a model for invasives with cheatgrass as an example
-USGS Northern Prairie Research Center also has some state-transition models
-Heartlands Network has some grassland conceptual models
-Grazing model paper from Roy Roath
-NRCS Ecological Site descriptions that incorporate state-transition models and are currently under development around the country. They may be willing to focus on park sites.

3.) Consider decomposition/microbial/soil animal interactions and belowground biomass in revised stressor models and new mechanistic models.
4.) Portions of the models mentioned in #2 above as well as the general grassland models should also be depicted as pictorial models. These models are information rich and easy to read and understand (see Figure 5 for an example). These types of models give the audience an overview of the system before getting into the details that are included the stressor and process models.
5.) Develop conceptual diagrams that are customized to a group of parks or in some cases individual parks. These will not be full models but will highlight the important components in information rich and aesthetically pleasing format that will increase understanding of the major grassland components and be useful for park managers and interpretive staff.
6.) Develop a prairie dog conceptual model. This species is important for management, biological, and cultural reasons at five SOPN parks. This model will include the prairie dog's affect on the flora (grazing), fauna (reduced cover that can create habitat for some rare species), disease (plagues can quickly decimate a colony), and management implications (colonies often abruptly end at NPS boundaries).
7.) Be sure to develop or borrow landscape vulnerability models. We will wait until other landscape level products that are being developed by other I+M networks are available before proceeding with the development of our own models. There are many grassland issues that are affected by landscape level issues, however these same issues are also likely to affect other terrestrial ecosystems (pinion-juniper, deciduous forest) and aquatic ecosystems (reservoir, rivers, streams, wetlands) which will be developed and assessed in late FY2005 and early FY2006.
8.) Keep the short-and mixed-grass stressor models because they show important links between drivers, stressors, ecological effects, indicators, and measures. Make the following changes to these stressor models:
    A.) Consider eliminating lines between components. If you thought long enough you could probably legitimately connect every component on the model. Too many connections makes the model too complicated. Specific important interactions can be shown on the detailed sub-models. Keep the model hierarchical (drivers, stressors, ecological effects, etc.) and keep things most associated in a linear fashion.

B.) Rename the elevation driver to topography to better represent slope, aspect, and elevation.
C.) Change grazing to herbivory/defoliation as grazing only implies impacts from ungulates. Herbivory/defoliation will incorporate many other processes can result in reduction of plant biomass (insects, ice storms, pathogens).
D.) Precipitation/temperature should be moved to a stressor. Leave climate as a driver that describes the long-term temporal scale and what makes a grassland as opposed to a forest. Precipitation and temperature will reflect the annual and seasonal variations in weather conditions.
E.) Insect outbreaks and wildlife diseases should be too separate stressors.
F.) Add carbon change and woody invasives as a potential measure under grassland community composition.
G.) Grassland birds should be added as a potential measure for wildlife and grassland indicators.
H.) Consider including the absence of keystone species (no wolves, more coyotes, less swift foxes).
I.) Write a more clearly defined narrative.

GRASSLAND ISSUES AND VITAL SIGNS

During the second day, the workshop divided into the same two working groups as the day before, mixed-grass and short-grass. The goal was our Access database that contained 73 issues that individual parks had raised during the 2004 scoping sessions and any additional issues that surfaced during our literature review. Each group ranked all of the issues as high, medium, low, or not an issue (Table 2 - Grassland Issue Ranking Results). Each group went to each of their highly ranked issue to review the possible vital signs, monitoring objectives and justification statements. Each group was also given half of the issue list to review as a starting point and then told to move on to the second half of the list if there was time. With this method each group reviewed all of their high ranking issues (most of these were the same between the two groups), and all of the remaining issues were reviewed by at least one group (most were reviewed by both groups).

In ranking each issue the breakout groups were given the following guidelines, an issue would only be ranked high or low if there was consensus among the group that it was high or low. This method resulted in a list of high priority issues that were most important across the entire network. Issues that were high priority to one park, but not highly ranked across the network, were captured by the individual park's ranking that occurred prior to the workshop. All issues that both groups ranked as low were dropped from future consideration as potential vital signs. All non-consensus issues were ranked medium. A fourth category, "not an issue" was created for issues that were important but could not be monitored in a meaningful way or did not fit the guidance for the inventory and monitoring program (budgets, lack of long-term management).

The breakout groups were in almost complete agreement with their rankings. The issues that ranked high for both groups were exotic plants, carbon balance, grassland plant community, prairie restoration, water quality, water quantity, weather patterns and invasive plant species. In addition, the short-grass group had four issues that they ranked high, but the mixed-grass group ranked as medium: effects of park visitors on natural resources, fire frequency, grassland birds, and viewshed. The mixed-grass group had two issues that they ranked high, but the short-grass group ranked as medium: erosion and exotic game. Ten issues were ranked as low by both groups and will be dropped from consideration as vital signs: Africanized honeybee, black-footed ferret, Colorado bursage, echinacea, feral cats, giant mole cricket, hazardous spill on adjacent land, marsh rice rat, Palo Duro Canyon mouse, and porcupine. The groups ranked two additional issues were ranked as "not an issue" by both groups: lack of funding and lack of long-term management planning.

Several new objectives and vital signs were recommended. The groups suggested combining two high ranked issues, grassland vegetation community and prairie restoration, into one issue because the same vital signs could be used for both issues. There was discussion in both groups that the grassland community issue should incorporate belowground processes, and that subsequent vital signs should incorporate grazing and fire processes. The groups suggested that carbon dioxide and nitrogen pathways, C3 and C4 grasses, and carbon balance were possible measures to answer some of these questions. The short-grass group also suggested that hunting should be eliminated as a stand-alone issue, and instead incorporate hunting concerns into the small mammals, game birds, and big game issues.

There was discussion regarding how cultural resource management issues that are affected by natural resources fits into the monitoring program (prairie dogs effects on Santa Fe Trail ruts, small mammals burrowing under ruins, landscape composition as it relates to viewsheds). The consensus was if the potential vital sign is only being considered because it affects a cultural resource, then it should not be part of the monitoring program. If the vital sign also affects an important natural resource then the cultural aspect may elevate the priority of that vital sign. As a result, viewshed and soundscape were eliminated as independent issues and will be incorporated into land cover/land use.

Three new issues were added to our database: carbon balance, keystone invertebrates, keystone vertebrate species, and meso-mammals/carnivores. Changes in carbon balance will precede other changes in ecosystem health and function. Carbon balance can be measured through soil respiration and productivity (NDVI – normalized distribution vegetation index). Some invertebrates can be keystone species and some introduced species (i.e. earthworms) can have drastic affects on biogeochemical feedbacks, soil processes, and altering trophic levels that can then affect flora and fauna. There are several keystone species that are important to individual parks (black-tailed prairie dogs, top predator [lack of], white-tailed deer). The meso-mammal issue was added by the mixed-grass group as an issue that would combine several other individual issues (porcupines, raccoons, swift fox). The group recognized that these meso-carnivores are an important part of the ecosystem and at many parks may represent the top trophic level that resides in the park (larger carnivores have home ranges larger then most SOPN parks).

At the conclusion of the workshop, a list of 53 issues related to grassland ecosystems was developed (Tables 3). In addition, the groups discussed issues related to grasslands, but will receive increased attention at our aquatic workshop or forested systems review (Table 3b). They were discussed at the grassland workshop because we recognize that some issues cannot be pigeonholed into only one particular type of ecosystem.

SOPN will hold a similar workshop this summer for aquatic systems, and will conduct the same process at a reduced level for forested systems (pinion-juniper and eastern deciduous forest). In fiscal year 2006, SOPN will evaluate the list of issues and vital signs developed at these workshops and prioritize, and then select the vital signs for our monitoring program.

Figure 1. Relationship (a) between Jenny's (1941) state factors and ecosystem processes, and (b) among state factors, interactive controls, and ecosystem processes. The circle represents the boundary of the system (Chapin et al. 1996).

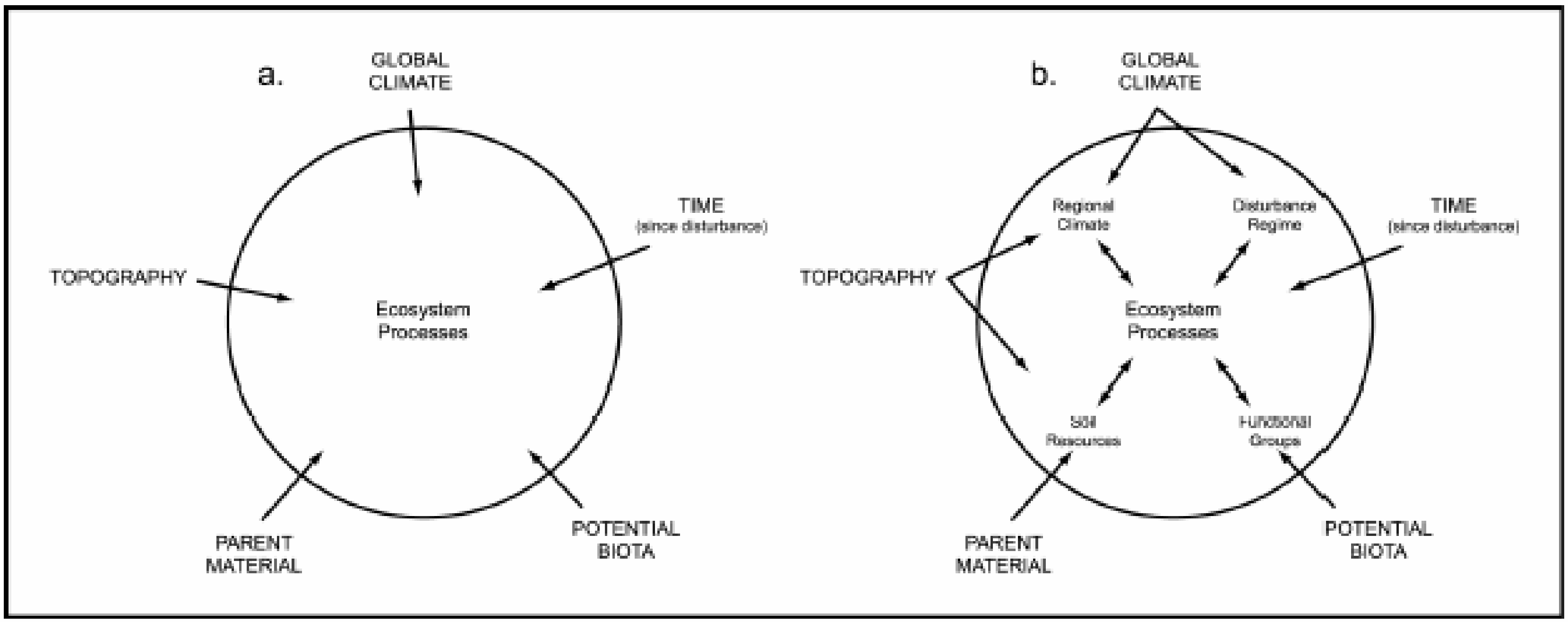

Figure 2. Short grass Breakout Group Simple Mechanistic Grassland Model

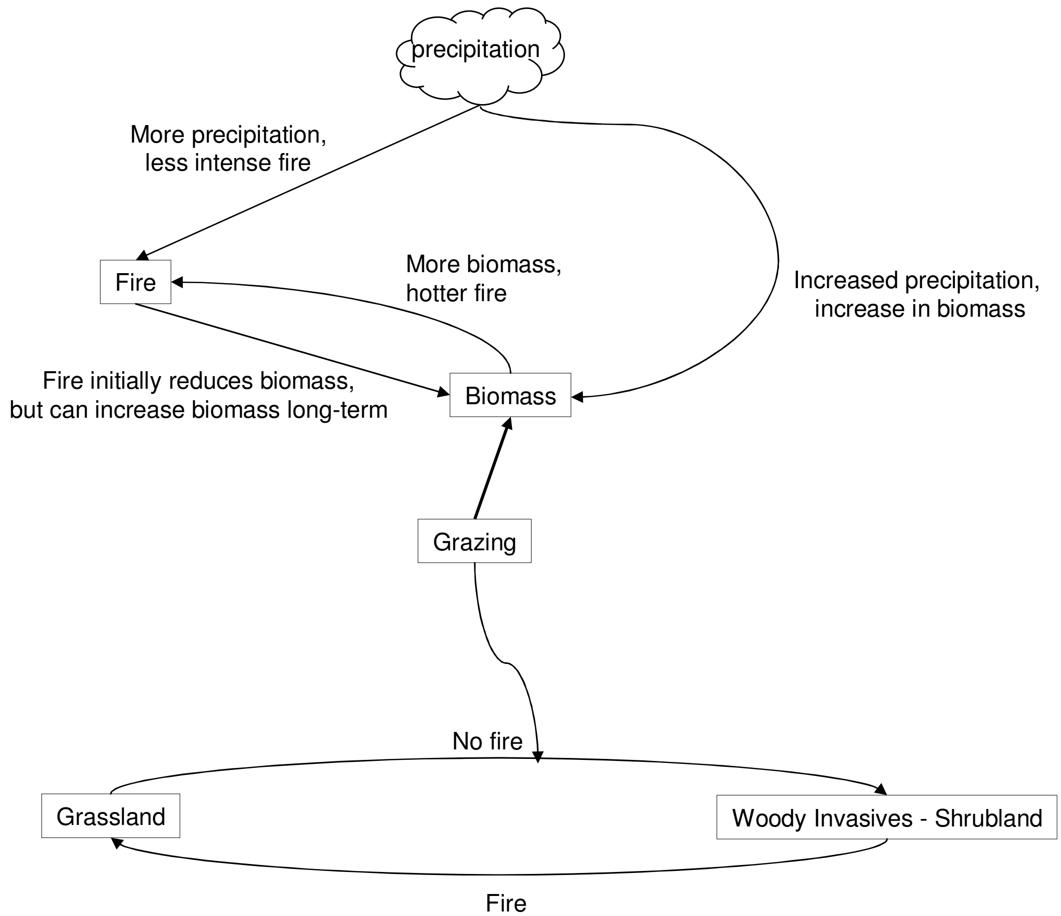

Figure 3. Rocky Mountain I+M Conceptual Model for grazing, fire interactions in grassland systems.

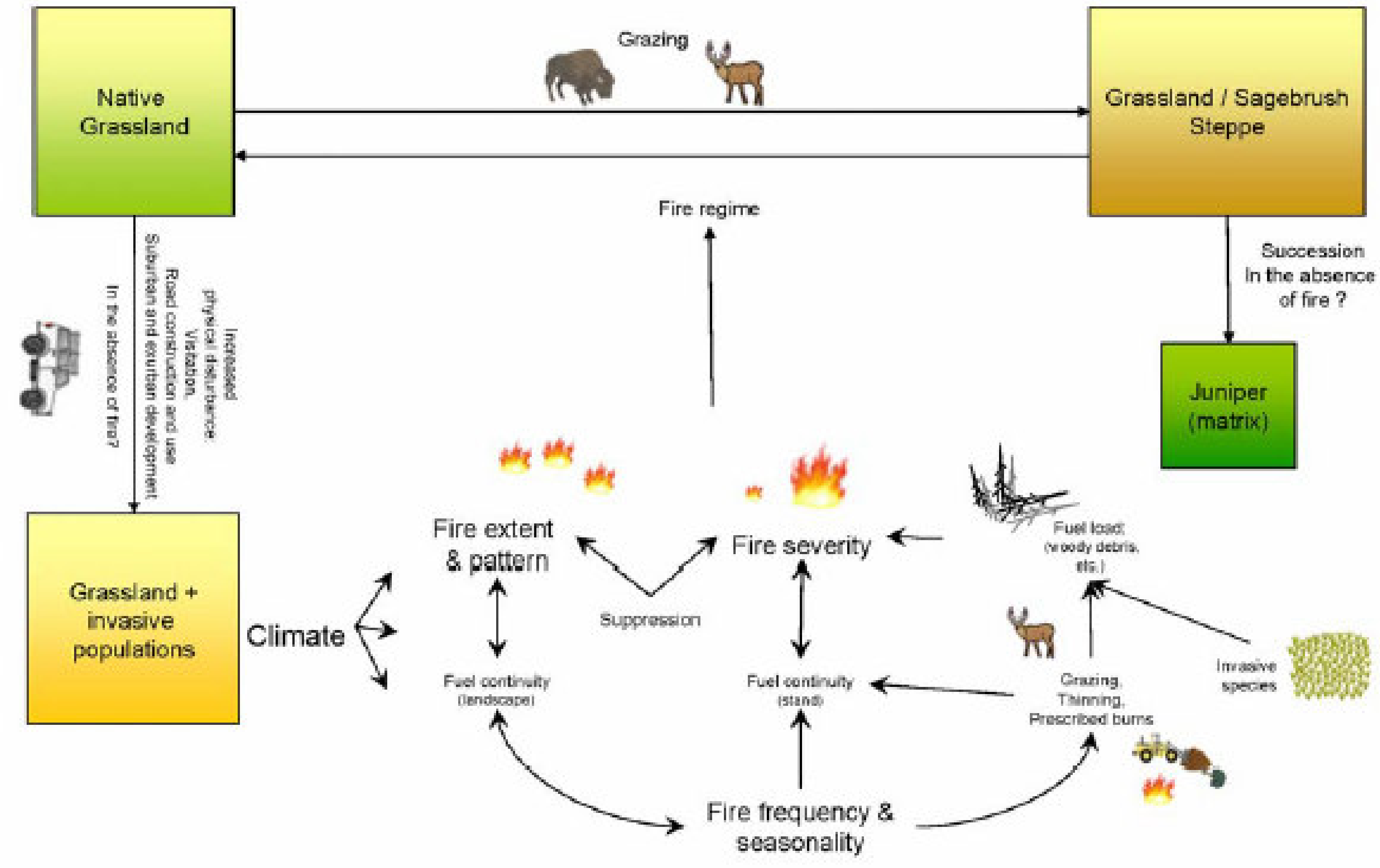

Figure 4. John Gross Grassland Model

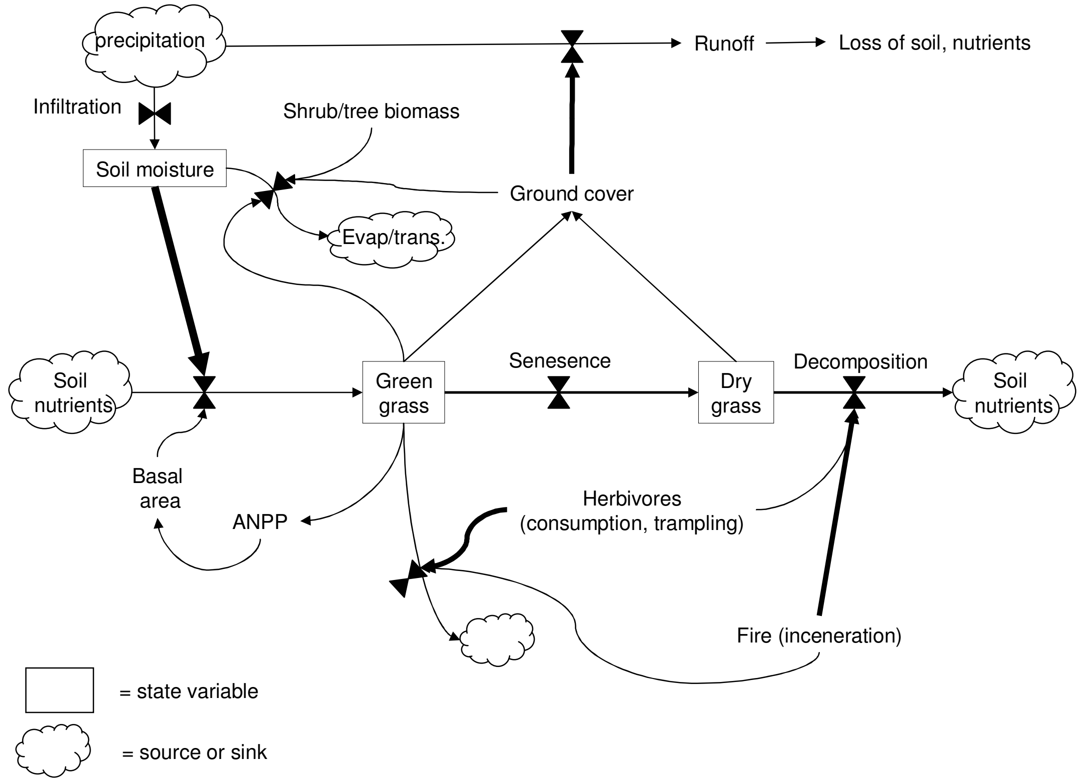

Figure 5. Example of pictorial conceptual model from the Southwest Alaska I+M Network.

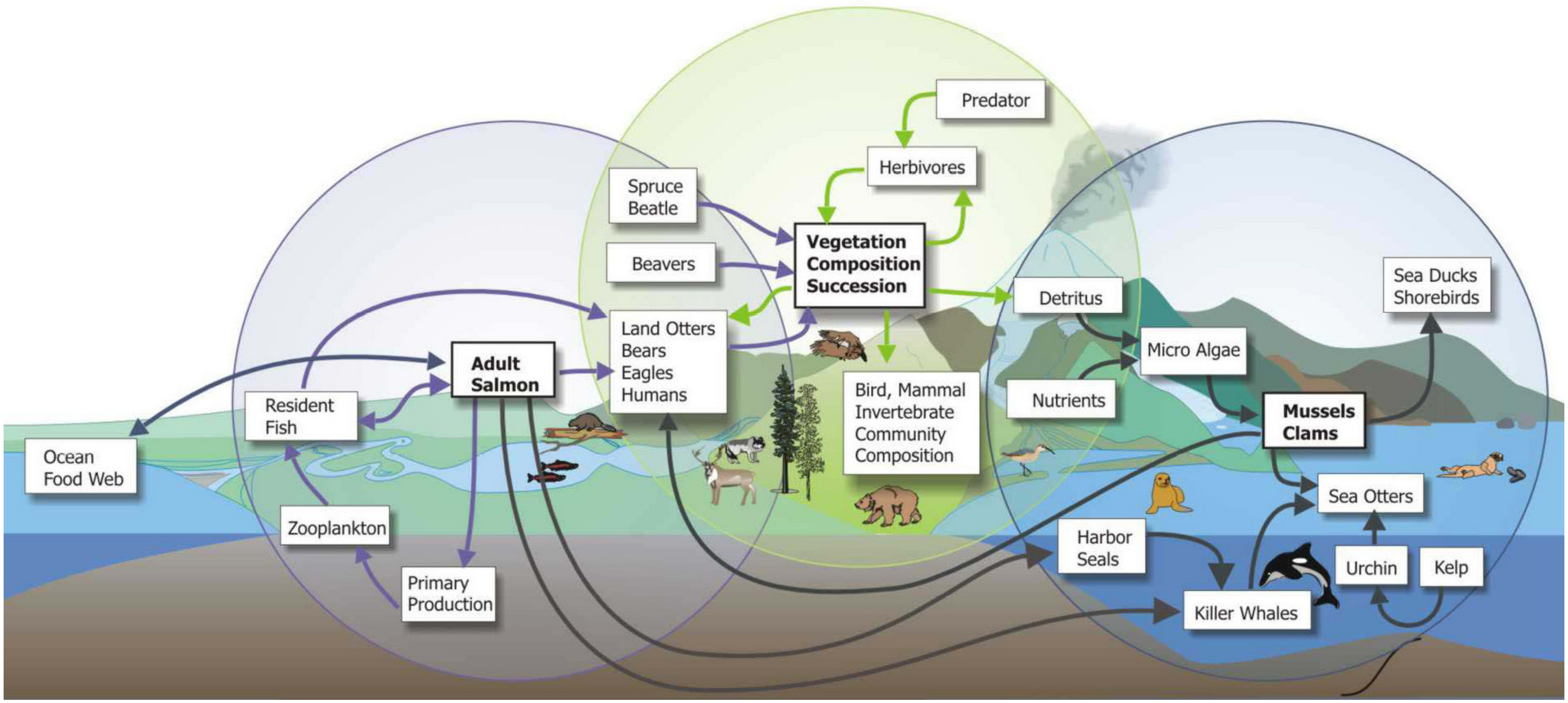

Table 1. Final Participant List

NPS Park Staff			
Person	*Position*	*Park*	*Breakout Session*
Ruben Andrade	Supervisory Park Ranger	Fort Union NM	Short-grass
Steve Burrough	Chief of Resource Management	Chickasaw NRA	Mixed-grass
Paul Eubank	Natural Resource Specialist	Lake Meredith NRA / Alibates Flint Quarries NM	Short-grass
Daniel Jacobs	Chief Ranger	Pecos NHP	Short-grass
Jason Lott	Integrated Resource Specialist	Lyndon B. Johnson NHP	Mixed-grass
Alden Miller	Chief of Resources + Facilities	Washita Battlefield NHS	Mixed-grass
Fran Pannebaker	Natural Resource Specialist	Bent's Old Fort NHS	Short-grass
Maggie Johnston	Superintendent	Capulin Volcano NM	Short-grass
Brian Quigley	Chief Ranger	Capulin Volcano NM	Short-grass
Karl Zimmermann	Park Ranger	Bent's Old Fort NHS	Short-grass
Felix Revello	Chief Ranger	Fort Larned NHS	Mixed-grass
Alexa Roberts	Superintendent	Sand Creek Massacre NHS	Short-grass
NPS Inventory and Monitoring Staff			
Person	*Position*	*Location*	*Breakout Session*
Dusty Perkins	SOPN Network Coordinator	Lyndon B. Johnson NHP	Floater
Heidi Sosinski	SOPN Data Manager	Lyndon B. Johnson NHP	Mixed-grass
Subject-Matter Experts			
Person	*Organization*	*Expertise*	*Breakout Session*
Dan Tinker	University of Wyoming	PI for Conceptual Models	Mixed-grass
Gail Stakes	University of Wyoming	Assisted with Model Dvlpt.	Short-grass
Linda Wallace	University of Oklahoma	Grazing-Plant Interactions, Plant competition	Mixed-grass
John Gross	NPS - Inventory and Monitoring Program	Conceptual Models, Landscape ecology	Short-grass
Tim Seastedt	University of Colorado-Boulder	Soil biodiversity, invasive plants	Short-grass
Karie Cherwin	University of Colorado-Boulder	SOPN Ph.D. Graduate Student	Short-grass
Sue Braumiller	NPS	Hydrology, aquatic model developer	Mixed-grass
Dan Licht	NPS – N. Great Plains Network	Grasslands, vertebrates	Mixed-grass
Steve Windhager	Ladybird Johnson Wildflower Center	Restoration, exotic vegetation	Mixed-grass
Brian Hajney	USFS-Black Kettle National Grasslands	Wildlife, grasslands	Mixed-grass
Roy Roath	Colorado State	Grazing Management, Rangeland monitoring	Short-grass
Kris Johnson	Natural Heritage New Mexico	Avian Conservation, Vertebrate Ecology	Short-grass

Table 2. Grasslands Workshop Issue Ranking Results

Total Number of Issues Ranked:	**74**
Issues Ranked "High" or "Medium":	**61**
Issues Ranked "Low" or "Not an Issue":	**13**

High

Issues were ranked as "High" priority only if both the mixed grass and short grass groups agreed. If an issue was ranked "high" by only one group, it was moved down to "Medium".

Carbon balance

Exotic Plants

Grassland plant community

Prairie Restoration

Water Quality

Water Quantity

Weather patterns

Woody Invasive Species

Medium

Issues were ranked as "Medium" priority under the following circumstances: Both groups ranked it as "Medium"; the issue was ranked "high" by one group and "Medium" by the other group; or the issue was ranked as "medium" by one group and "Low" by the other group.

Adjacent Land Use

Air Quality

Alberta arctic butterfly

Bald Eagle

Big Game

Black-tailed prairie dogs

Boundary survey/fencing

Burrowing owl

Cryptobiotic soils

E.coli levels

Effects of Grazing

Effects of Park visitors on natural resources*

Endemic invertebrates

Erosion^

Exotic Game^

Feral Dogs

Feral Hogs

Ferruginous hawk

Fire*

Fire Ants

Game birds

Grassland birds*

Groundwater levels

Hunting

Insect diseases on ecosystem

Lacustrine Community

Large Carnivores

Lesser Prairie Chicken

- Medium sized mammals
- Meso Mammals / Carnivores
- Migratory songbird stopover area
- Mineral, Oil, and Gas Extraction
- Mississippi Kites
- Mountain plovers
- Montane/grassland/desert interface
- Night sky
- Non-vascular plants
- Nutria
- Off-road vehicle use
- Pollution from non-park sources
- Raccoons
- Reptile Community
- Small mammal community
- Soundscape
- SW Willow flycatcher
- Swift fox
- Texas horned lizard
- Townsend's big eared bat
- Viewshed*
- Volcanic Cinder Cone
- Upland Springs
- Wetlands in upland systems
- Wildlife Diseases effects on staff and visitor

* denotes a high ranked issue by the short-grass group but a medium ranking by the mixed-grass group

^ denotes a high ranked issue by the mixed-grass group but a medium ranking by the short-grass group

Low

Issues can be ranked as "Low" priority only if both the mixed grass and short grass groups both agreed on that ranking.

- Africanized honeybee
- Black-footed ferret
- Colorado bursage
- Echinacea
- Feral Cats
- Giant mole cricket
- Hazardous spill on adjacent highway, railroad
- Marsh rice rat
- Palo Duro canyon mouse
- Porcupine

Not An Issue

These are issues are not directly related to vital signs monitoring.

- Funding (lack of money and staff)
- Lack of long-term management plan

Table 3a. Final List of Grassland Issues. These issues are being considered as potential vital signs for grassland systems. They are shown here according to their proposed classifications within the National Vital Signs classification system.

Level 1	Level 2	Level 3	Issue Name
Air and Climate	Air Quality	Air contaminants	Air quality[1]
	Weather and Climate	Weather and climate	Weather patterns[1]
Biological Integrity	At-risk Biota	T&E species and communities	Alberta arctic butterfly
			Bald eagle
			Black-tailed prairie dog
			Burrowing owl
			Ferruginous hawk
			Lesser prairie chicken
			Mountain plovers
			Southwestern willow flycatcher
			Swift fox
			Texas horned lizard
			Townsend's big-eared bat
	Focal Species or Communities	Keystone species	Specific keystone species
		Amphibians and reptiles	Reptile community
		Birds	Grassland birds
			Migratory songbird stopover area
			Mississippi kites
		Grassland vegetation	Grassland community (includes prairie restoration)
		Mammals	Large carnivores
			Large ungulates
			Meso mammals / carnivores

Level 1	Level 2	Level 3	Issue Name
Biological Integrity	Focal Species or Communities	Mammals	Raccoons
			Small mammal community
		Terrestrial invertebrates	Endemic invertebrates
			Keystone invertebrates
		Vegetation communities	Non-vascular plants
			Montane/grassland/desert interface
	Infestations and Disease	Animal diseases	Wildlife diseases effects on staff and visitors
		Insect pests	Insect diseases on ecosystem
			Fire ants
	Invasive Species	Invasive / exotic animals	Exotic game
			Feral dogs
			Feral hogs
			Nutria
		Invasive / exotic plants	Exotic plants
			Woody invasive species
Ecosystems Patterns and Processes	Fire	Fire and fuel dynamics	Fire
	Land Cover and Use	Land cover and use	Boundary survey / fencing
			Land Use / land cover[1]
			Adjacent land use[1]
	Nutrient Dynamics	Nutrient dynamics	Carbon balance

Level 1	Level 2	Level 3	Issue Name
Geology and Soils	Geomorphology	Stream / river channel characteristics	Erosion[1]
	Soil Quality	Soil function and dynamics	Cryptobiotic soils
	Subsurface Geologic Processes	Volcanic features and processes	Volcanic cinder cone[1]
Human Use	Consumptive Use	Consumptive use	Effects of grazing
			Game birds
			Mineral, oil, and gas Extraction
	Non-point Source Human Effects	Non-point source human effects	Pollution from non-park sources[1]
	Visitor and Recreation Use	Visitor usage	Effects of park visitors on natural resources
			Off-road vehicle use
Water	Hydrology	Groundwater dynamics	Groundwater levels[1]
	Water Quality	Microorganisms	E. coli[1]

Table 3b: Aquatic issues that were discussed briefly at the grasslands workshop and will be discussed in more detail at the aquatic workshop.

Level 1	Level 2	Level 3	Issue Name
Biological Integrity	Focal Species or Communities	Freshwater communities	Lacustrine community
		Wetland communities	Wetlands in upland systems
Water	Hydrology	Groundwater dynamics	Upland springs
	Water Quality	Surface water dynamics	Water quality
			Water quantity

Appendix 1. Narrative and pictures of draft conceptual models developed by Dr. Dan Tinker and Dr. Ann Hild and presented at the grassland workshop.

Short grass and Mixed grass Ecosystems in the Southern Plains
A Narrative Conceptual Model

Prepared by Daniel Tinker and Ann Hild
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Laramie, Wyoming

Introduction

Grasslands were historically the largest vegetation type in North America, covering more than 300 million ha (Küchler 1964), yet still occupy over 125 million ha in the United States (U.S. Forest Service 1980). However, short grass and mixed grass prairie grasslands are currently some of the most endangered ecosystems in North America (Rickletts et al. 1999). Short grass prairies are dominated by two species of grass, *Bouteloua gracilis* and *Buchloë dactyloides*, but other species such as *Stipa comata*, *Koeleria macrantha*, and *Sporobolus cryptandus* are also important components. These ecosystems are found primarily east of the Rocky Mountains, from Nebraska and Wyoming southward through the High Plains (Sims and Risser 2000). Mixed grass prairies, which extend from south-central Canadian provinces to central Texas, are more floristically rich, and are characterized by vegetation intermediate to tallgrass and short grass prairies. Dominant species vary across a latitudinal gradient, and include species of *Elymus*, *Pseudoroegneria*, *Bouteloua*, along with various species of sedges (*Carex* sp.) (Barbour et al. 1987).

Conceptual Model Development

Drivers

The **climate** found in short grass and mixed grass ecosystems is quite variable across central North America. Notably, in the majority of these systems, approximately two-thirds of the annual rainfall in central grasslands occurs during the growing season (Sims et al. 1978). The usual rainfall deficiency that occurs late in the growing seasons provides conditions more favorable for the maintenance of grasslands than to deciduous forests (Sims and Risser 2000). In particular, grasslands of the Great Plains are strongly influenced by north-south and east-west climatic patterns, with precipitation decreasing from east to west, and air temperature increasing from north to south (Singh et al. 1983). Precipitation also acts as a strong driver of grassland ecosystem processes, and the relationship between rainfall and productivity is generally linear (Lauenroth 1979). The distribution of grasslands within the central U.S., as well as their vegetative composition, is further related to the interactions of a variety of other environmental and edaphic factors, including physiographic and topographic conditions, **elevation**, and herbivory (McNaughton, Coughenour, and Wallace 1982). With respect to **bedrock geology and**

soils, Mollisols are typically associated with cool, wet grasslands of the central plains, while more arid sites are most often characterized by Aridisols (Sims and Risser 2000). In the southern plains, soil texture varies from fine sandy soils to clay soils. There is a swath of relatively fertile Alfisols that stretches from southeastern Kansas into central Texas, following the general distribution of the cross timbers vegetation, as mapped by Küchler (1984), while Mollisols are most abundant throughout the rest of the southern plains (Sims and Risser 2000).

Stressors

Wet and dry cycles, along with periodic **drought** in short grass systems, may be both harmful and beneficial, depending on the timing and intensity of the cycles. Dickinson and Dodd (1976) found that increases in water may affect the phenology of some grass species, e.g., *Bouteloua gracilis*, and flowering may occur earlier than in drier periods. Notably, some grassland systems have developed adaptations to aridity, which may manifest themselves as morphological changes such as small stature and basal meristems (Coughenour 1985). These adaptations may also be advantageous for recovery from herbivore grazing. In general, grassland ecosystem responses to **grazing** are quite variable, and many systems have evolved grazing resistance to herbivory (e.g., Milchunas and Lauenroth 1993). However, grazing may be detrimental to many short grass and mixed grass ecosystems, depending on the intensity and duration of the grazing activity.

Erosion of surficial soils may occur as a result of intense, episodic rainfall events, or from road building, agricultural activities, and other human land uses. Stream bank erosion may also occur from human land use practices such as grazing. Excessive grazing, which can cause increases in bare ground, may be positively correlated with increases in runoff following precipitation events (Hart et al. 1988; Hart and Frasier 2003). Similarly, **flooding** of rivers and streams can occur in arid areas where human activities have rerouted water courses and where soil texture prevents rapid infiltration.

Fire may also be a stressor, although most grassland systems have evolved with relatively frequent recurring fires (Sauer 1950; Curtis 1962; Alelrod 1985). Consequently, the suppression and removal of fire as an ecological process could actually act as a more direct stressor than fire itself, although fire may be detrimental in some short grass prairie ecosystems (Wright and Bailey 1980).

Invasive exotic plant species may colonize disturbed areas in and around NPS lands, and can be transported into parks via humans, vehicles, or other biotic vectors. These plants may outcompete some native vegetation and persist for decades. **Exotic animal species** and feral domestic species can also compete with native species for limited resources. Along with invasive species, **insect and wildlife diseases**, both natural and exotic, may infest native populations of plants and animals. While they may not be exotic, black-tailed prairie dogs and their colonies may play a significant role as a stressor in avian community structure and composition in some areas of short grass plains

(Smith and Lomolino 2004), and their presence may be either beneficial or detrimental to other fauna and flora.

A critical stressor that could, in many ways, also be considered a driver, is **human impacts** and **adjacent land use and land use change**. The many different ways that humans use the land is an important contributor to landscape pattern and process (Turner et al. 2001). For example, residential, commercial, and industrial development on adjacent lands are the direct result of human use (Meyer 1995), and may create hard boundaries around parks that can interrupt natural flows and fluxes of ecosystem processes and services, including recycling of nutrients and maintenance of clean air and water – this may be particularly problematic for some of the smaller parks in the Southern Plains Network. Many of the historically intact landscapes are rapidly becoming fragmented, largely through human land uses (Harris 1984). Unfortunately, these human "footprints" on the landscape are usually one-directional and are long-lasting legacies on the landscape (Turner et al. 1988). Species-area relationships are important for identifying biodiversity hotspots (Myers et al. 2000), and for helping predict reductions in populations or species in areas subjected to habitat fragmentation (Pimm and Askins 1995). This increases the difficulty in managing small areas, as are common for some parks within SOPN. Closely related to human land uses is the issue of **non-park source pollution**, which may include a variety of unwanted materials such as fertilizers and airborne pollutants.

Ecological Outcomes and processes

Ecological outcomes and processes describe complex, interactive relationships between various biotic and abiotic components of the ecosystem. These processes are more fully explained by way of individual schematic submodels, and include many of the drivers, stressors, and indicators discussed in this narrative.

Indicators

Bird and other wildlife populations are directly and indirectly affected by many of the stressors contained in the animal population dynamic submodel, including human impacts such as land use change, and the invasion of exotic and feral species. Inventories of big game, ungulates and other small mammals may serve as important indicators of ecosystem function. The interactions of temperature, precipitation, and soil type, along with annual and decadal wet and dry cycles can determine the structure and activity of **wetland areas and upland springs**.

Regeneration of **Cottonwood riparian woods** relies heavily on episodic flooding events. Regulation of water flows, through impoundments and irrigation, may reduce the likelihood of such events and, consequently inhibit natural regeneration of new individuals along these important corridors. In mixed grass ecosystems, small patches of **deciduous hardwood forests** are quite sensitive to many stressors such as human impacts, grazing and invasive plant species.

Grassland community composition is an excellent indicator of the condition of these ecosystems. Further, resource islands in temperate grasslands, which develop from spatially heterogeneous plant cover, can be areas of accumulated soil materials. These islands may take decades to create, but can disappear within three years of the death of an individual plant, and may be good indicators of ecosystem condition (Burke et al. 1998). Further, the **habitat quality** of the grassland ecosystems responds to a variety of drivers and stressors, most notably human impacts, grazing, and periodic drought.

Water quality and quantity respond to a myriad of drivers and stressors. **Water quantity** is directly affected by annual precipitation and periodic drought, along with water allocation by human uses. **Water quality** may be impacted by specific non-park source pollution, and also by non-point source pollution such as atmospheric deposition. **Night skies and soundscapes**, arguably some of the most desired resources in national parks and recreation areas, are primarily affected by human impacts and adjacent land uses, including construction of roads and buildings. Other impacts to soundscapes can include fire suppression efforts. However, night skies may also be impacted by other natural causes such as dust, which may be caused by periods of drought.

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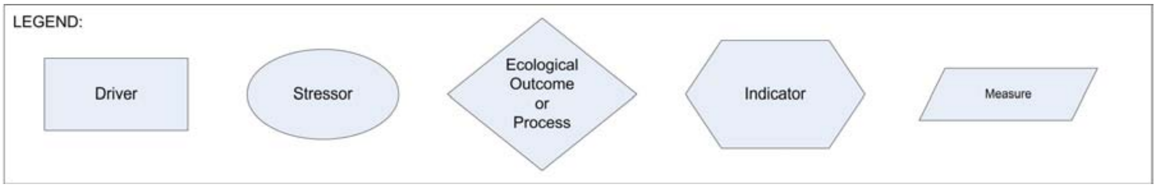
Conceptual Models



- DRIVER – The major external driving forces that have large scale influences on natural systems. Drivers can be natural forces or anthropogenic.

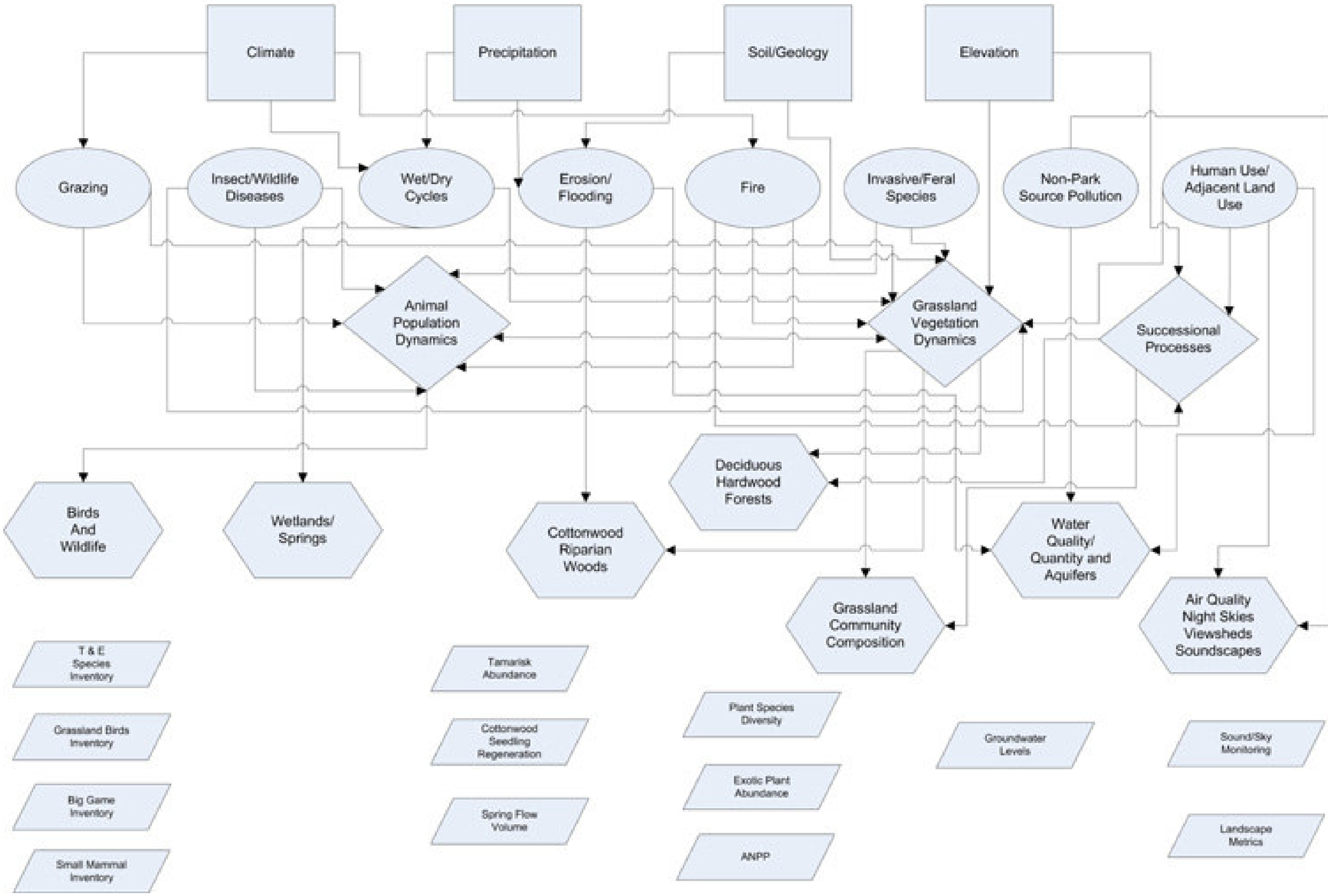
- STRESSOR – Physical, chemical, or biological agents that cause significant changes in the ecological components, patterns and relationships in natural systems. The effects of stressors on park resources can be positive or negative.

- ECOLOGICAL OUTCOME OR PROCESS – Physical, chemical, and biological/ecological responses to drivers and stressors.

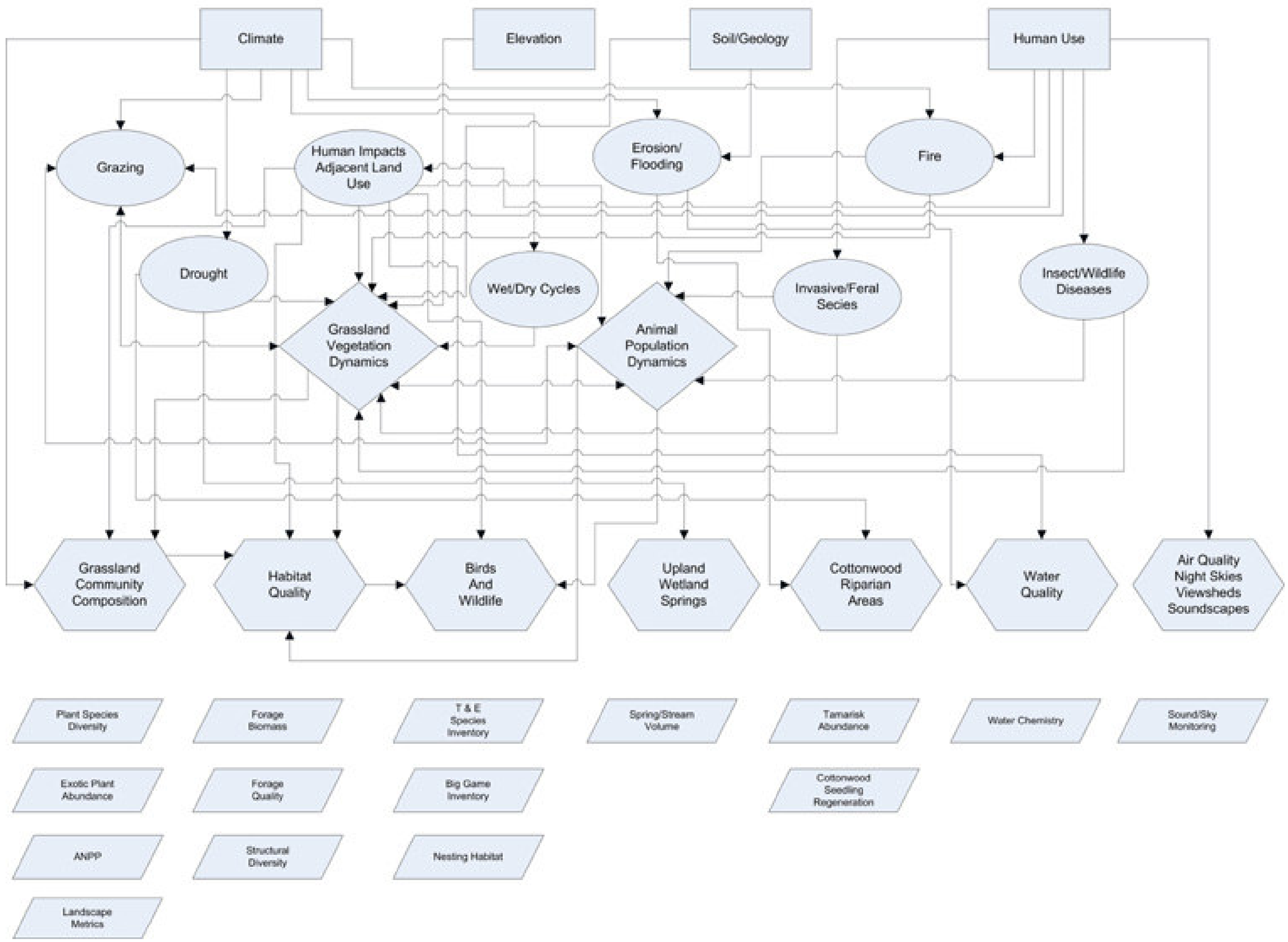
- INDICATORS – Any living or nonliving feature of the environment that can be measured or estimated and that provides insights into the state of the ecosystem. Indicators are sometimes defined as a subset of attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong.

- MEASURES – Specific measures used to quantify the indicators. Analysis of this information will assess how well the indicator is responding to the ecological effect.

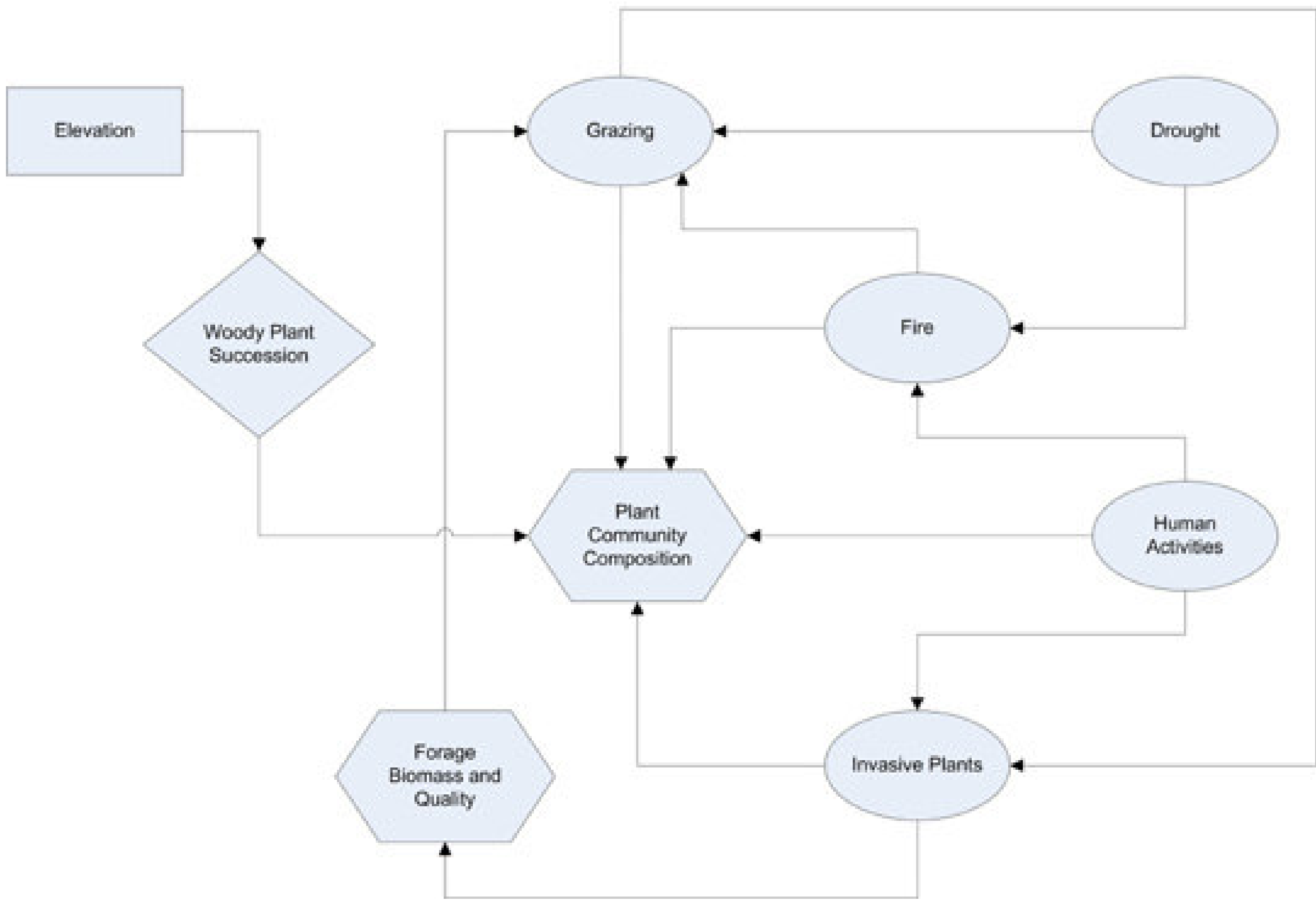
Mixed Grass Ecosystem Model



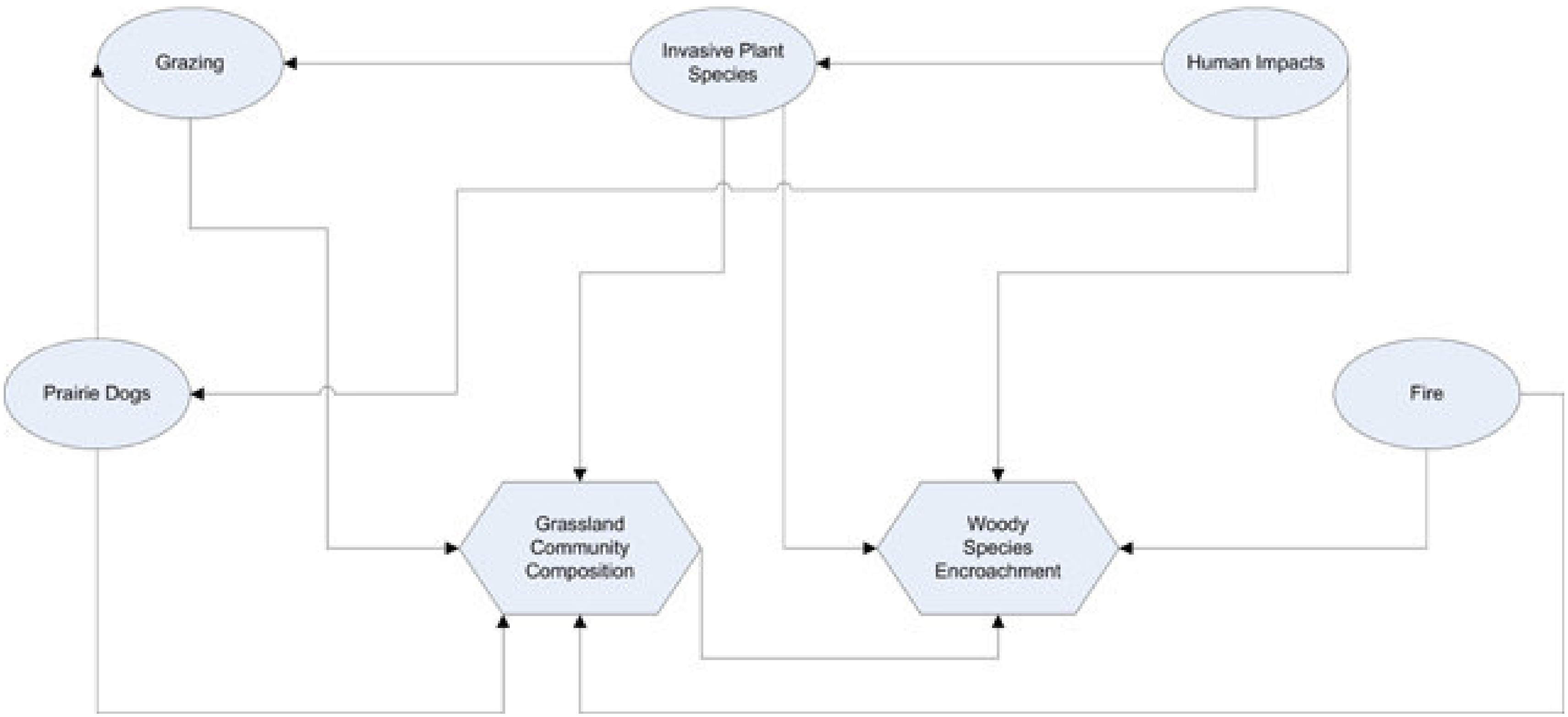
Short Grass Ecosystem Model



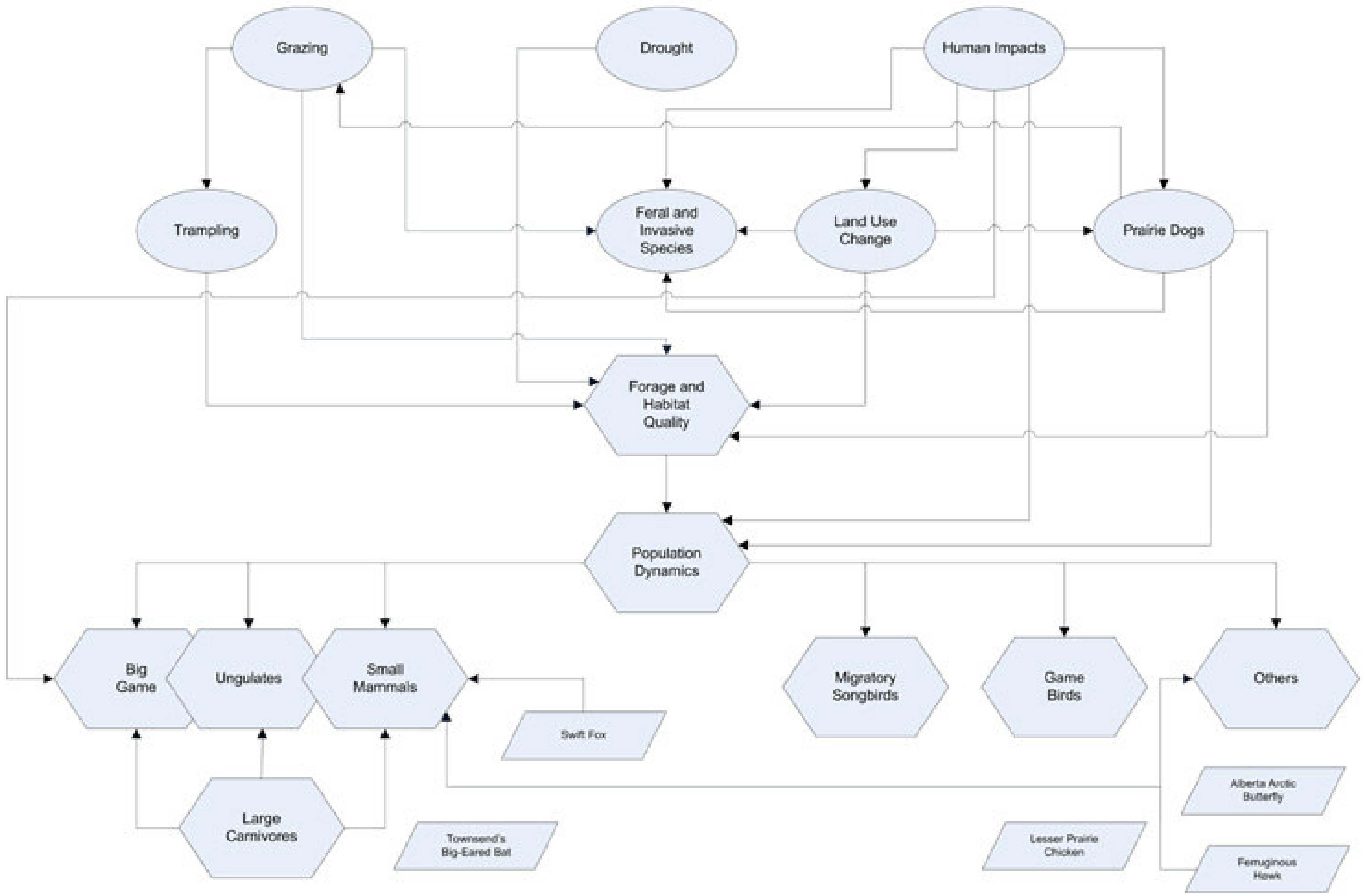
Vegetation Dynamics Submodel



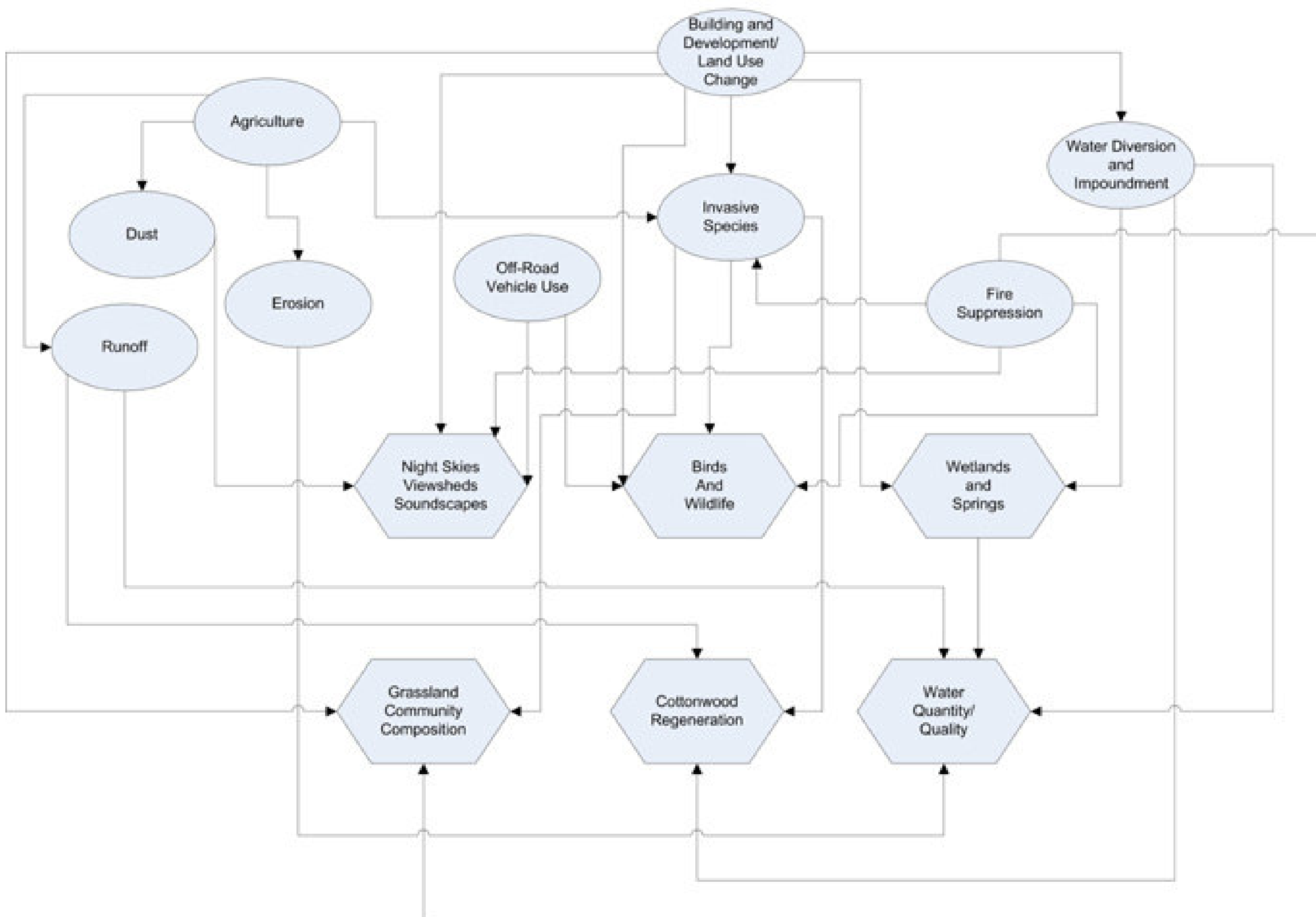
Successional Processes Submodel



Animal Population Dynamics Submodel



Human Impacts Submodel



Appendix 2. Reviews of conceptual models from breakout groups, comments on feedback forms, and comments on model drawings.

Short grass Breakout Group

Comments for Short grass Model – The group agreed that the stressor model type was useful as an overarching model, but some additional models would add more information, organizational clarity and management assistance.

The group suggested adopting the Jenny-Chapin Model (Figure 1) either as is, or with slight modifications pertinent to SOPN. This would give all an understanding of the overall processes and elements that pertain to any conceptual model within SOPN (grassland or other).

In addition to the stressor models developed by Dr. Tinker, they suggested building some additional, more process based models that emphasize the major interactions, rather then try to characterize all interactions in the process model. Park staff participants in particular thought that more process or mechanistic models would be more useful in relating them to management. The group built a simple example of a grassland mechanistic model (Figure 2). An example from the Rocky Mountain Network (Figure 3) was put forward, as well as a model developed by John Gross (Figure 4) as examples. These types of models will do a better job of showing the temporal effects of the stressors, which is hard to show in a stressor model.

For a primary driver the group suggested using topography instead of elevation. They also suggested changing grazing to defoliation recognizing that defoliation can be due to insects, weather disturbances, etc. as well as large ungulates. Below-ground biomass and soil microbiology are very important and should be added to the existing stressor models and incorporated into the new process/mechanistic based models. In the short grass model, grassland birds and keystone species should be added as measures to the list of potential vital signs under the birds and wildlife indicator, and woody invasives should be added as a measure under the grassland community composition indicator. They thought that wet and dry cycles should be combined with drought, and if they are not combined, then the differences should be thoroughly explained in the narrative.

The group wanted to see a more clearly defined narrative in the final product. This narrative should have more details and clearly define the processes (nutrient turnover in successional processes). The vegetation dynamics and animal sub-models needed a narrative to be more useful.

Comments for Sub-Models – The group suggested combining the successional process and vegetation dynamics submodels into one model. The group suggested developing a land-use, land-cover conceptual model, however Dusty Perkins explained later that we will probably look to tackle this type of model at a later date as landscape level models will also affect other ecosystems in addition to grasslands. SOPN had originally planned to pursue a landscape vulnerability model, but John Gross (WASO I+M) had persuaded SOPN to wait until several other landscape projects are completed by other networks to see what we can use from those projects. The group emphasized that this was an important topic to tackle in the future. The group thought that some of the process based models described above should be developed for fire and grazing interactions instead of the stressor type models. These fire and grazing models should capture variables like time of year, extent, intensity, and preceding (legacy) conditions.

There was some debate over whether there should be a prairie-dog specific animal model given their importance as a rare keystone species with large management implications. Are there other keystone species that models should also be developed for? The group thought that the grassland vegetation and animal population dynamics model needed more explanation.

Mixed-grass Breakout Group

Comments for Mixed-Grass Model – This group spent the majority of their time going through the specifics of the mixed-grass stressor model, by looking at drivers, stressors, ecological outcomes, indicators, and measures.

-Climate Driver – The model should include temperature and precipitation as stressors connected to climate, the latter is currently listed as an individual driver. If precipitation is included as a separate driver, clarify the differences from climate. Climate is more of a long-term temporal scale, setting the ecosystem to be a grassland instead of forest, while temperature and precipitation are more like weather, they are short-term changes affecting the vegetation in the grassland. The model should include/consider wet/dry cycles (amount, timing), precipitation quality (example: nitrogen, acid levels in rain, snow), precipitation variability (timing may affect different species differently), vegetation interactions with precipitation variability and intensity (example: buffalo grass sheds rain, leading to more runoff). This climate/precipitation/temperature could be turned into a state transition model.

-Elevation Driver – This should be changed to topography that would include slope, aspect, lat/long, other physiographic characteristics.

-Soils and Geology Driver – Soils should be considered more as a driver (example: past land use and its affect, certain uses may have changed soil characteristics, preventing the return of grassland. Farmland is harder to restore then ranchland because the soil has been disturbed on farms) and could be its own separate driver or stressor, soils can affect the vegetation present, hence affecting the species present. Should be up somewhere at the top. This legacy of past land use should be more of a driver than a stressor (a stressor is an agent that causes significant change, while a driver is a major external force, i.e. a legacy condition not a transient condition)

-Grazing Stressor - should be changed to herbivory

-Insect/wildlife Diseases Stressor – What is meant by this stressor? Insect outbreaks, ips beetle? Lack of insects could also be a problem. Wildlife diseases (hanta virus, west Nile virus) should be a separate stressor or removed and renamed to pathogens that implies the focus is on the wildlife impacts of diseases.

-Arrow Connection Comments – The group suggested several new ways to draw new arrows connecting components of the model: wet/dry cycles and erosion/flooding, wet/dry cycles to fire both ways, fire regime to grassland vegetation dynamics both ways, animal dynamics can affect cottonwood and forest regeneration. The group debated if the chart would become too busy if we connect drivers to drivers, stressors to stressors. The current model is pretty simple. Could take two approaches, one approach would connect the major components and mention in text that other components connect. Models are difficult in that you strive for simplicity, but you still want to be inclusive (a paradox).

The second approach was to remove all connections, group items drivers, stressors, indicators, etc. and connect the groups with arrows. Specific arrows and connections could be incorporated into the submodels.

-Question – Cultural resource management and how it affects natural resource management, is there a good place on the model to capture this? (Example: prairie dogs on Santa Fe trail ruts, landscape composition and its relation to viewsheds, small mammals burrowing under ruins). If or when should these issues be included in priority ranking of vital signs. This topic fits better in the human impact sub-model than in the overall mixed-grass model. If the potential vital sign is only included because it affects a cultural resource, then it should not be a vital sign. If the vital sign also affects an important natural resource then the cultural aspect may elevate its priority.

General Comments

-Rename cottonwood riparian woods to "Riparian Woods".

-Absence of keystone species (example: wolves can have a trickle down effect upon an entire system, more wolves = less coyotes = affect small mammal abundance). Keystone species should be added to the animal population sub-model?

-Smaller parks – Adjacent land use or non-park source pollution is an issue.

-Human use and adjacent land use – accounts for affect of fragmentation. Plan on developing at some point a landscape vulnerability conceptual model.

- Combine vegetation dynamics and successional sub-model processes into a state transition model.

Candidate Vital Signs/Indicators

-Birds and Wildlife – need to make sure we consider not just the animal, but the habitat of the animal. Monitor community composition, but what does that tell you about habitat? Any habitat process starts with at least three different species that can use the habitat. Gather the data right and you can use it for a number of species. Get some basic criteria (example: canopy cover). Does it include exotics, do you sample differently? Each park needs to decide what communities to measure to get statistically relevant results.

-Candidate indicators – Vegetation community composition, rare and invasive plant species, animals of management concern (T&E, invasive, others as important to the park; keystone species for trend monitoring (i.e. small mammals, ungulates).

-Candidate indicators – May want to monitor birds, hogs, etc. because they are important to park management, even though they are not effective habitat indicators. In some cases, species presence/absence may be an easier to measure (example – amphibians).

-Candidate indicator – Carbon balance (are parks a net source or sink for CO_2?). There are various ways to measure (example: satellite imagery, soil sample testing). Monitoring CO_2 from the soil. This is a good indicator of ecosystem health and is applicable across all parks.

Model Comments on Posters and Feedback Forms

Mixed-Grass Model

-The water quality/quantity indicator should include/consider both surface water and ground water.
-Carbon balance should be a measure for the grassland community composition indicator.
-Reptiles should be a measure for the birds and wildlife indicator.
-Human management could be included in the human use/adjacent land use stressor.
-Park-source pollution (e.g. E. coli) should be added to Non-park source pollution
-Invasive/exotic plants should be separate stressor from exotic animals
-The elevation driver should be renamed topography, which would incorporate slope, aspect, and elevation.
-Precipitation should be stressor underneath climate. Climate is long-term, where things like precipitation and temperature fluctuate annually and seasonally.
-Additional arrows were drawn from animal population dynamics to deciduous hardwood forest, cottonwood riparian woods, and grassland community composition.
-Double arrows were drawn connecting: erosion/flooding to vegetation dynamics; grazing to invasive/feral species; grazing to fire; grazing to erosion/flooding, wet/dry cycles to erosion/flooding
-Modified or tool might be better term then stressor which implies negative connotation.

Short-grass Model

-Precipitation should be stressor underneath climate. Climate is long-term, where things like precipitation and temperature fluctuate annually and seasonally.
-The elevation driver should be renamed topography, which would incorporate slope, aspect, and elevation.
-Erosion indicators can be good. These can change due to overgrazing, exotics, etc, can affect overland flow.
-Grazing should include herbivory.
-Human use driver should include land legacy (what is starting point, agricultural field, prairie fragment, overgrazed land).
-Carbon balance should be a measure for the grassland community composition indicator.
-Woody invasives should be a measure for the grassland community composition indicator.
-Grassland bird species richness and abundance and keystone species should be a measure for the birds and wildlife indicator.
-Additional arrows were drawn to connect: drought to wet/dry cycles; elevation to animal population dynamics.
-Modifier or tool might be better term then stressor, which implies negative connotation.
-A gap in our knowledge is the effects of invasive species, we can use model to generate hypotheses, but not for predictions.
-Submodels will need to have site-specific spatial analyses.
-This person preferred climate, topography, geology, time/land legacies, and human/biota as drivers. Soils are an interaction response of the drivers. Adding a “biotic” to human use allows for source identification of invasive/feral species. Time/legacies allow for acknowledgement of historical effects.

-The model ignores decomposition/microbial/soil animal interactions. This can be ok if: a) impacts are adequately captured by other interactions, and b) the biota in this group doesn't radically change and change their impacts (e.g. invasive earthworms in riparian zone).
-Westoby et al. Journal of Range Management was suggested as a good state-transition model for fire and grazing
-Submodels should consider interactions with invasive species and woody species Evans et al. 2001 had a model for invasives with cheatgrass as an example

Vegetation Dynamics Submodel
-Change to state-transition model.
-Temperature was added as a stressor and lines from it were drawn to grazing, drought, fire, plant community composition, forage and biomass quality, woody plant succession, human activities, invasive plants, drought, and elevation.
-Burrowing and pollination was added as a stressor and lines from it were drawn to grazing, plant community composition, forage and biomass quality

Successional Processes Submodel
-Change to state-transition model with thresholds.
-Include biomass, both above and below ground.
-Why were prairie dogs included as a separate stressor? Is this too specific?
-Climate and time cycles should be incorporated.
-Disturbance, frequency, intensity, and homogeneity should be included in fire.
-Additional line drawn between grazing and prairie dogs.

Animal Population Dynamics Submodel
-Temperature should be added as a stressor and connected to grazing, drought, and feral and invasive species.
-Grazing should be changed to herbivory.
-Disease should be added as a stressor and connected to prairie dogs.
-Should prairie dogs have a whole separate submodel?
-Grazing should connect to prairie dogs.
-Drought should be renamed wet/dry cycles.
-Other prairie birds and herps should be added as indicators.
-The population dynamics indicator should connect to lesser prairie chicken and Alberta arctic butterfly.

Human Impacts Submodel
-Climate change added as a stressor
-Prescribed fire added as a stressor
-Arrow connecting off-road vehicle use to erosion
-non-point source pollution and recreational pollution (e.coli, sewage leaks into streams) should be added as a stressor